Physical and Optical Characterization of Polymer Surfaces

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The Problem

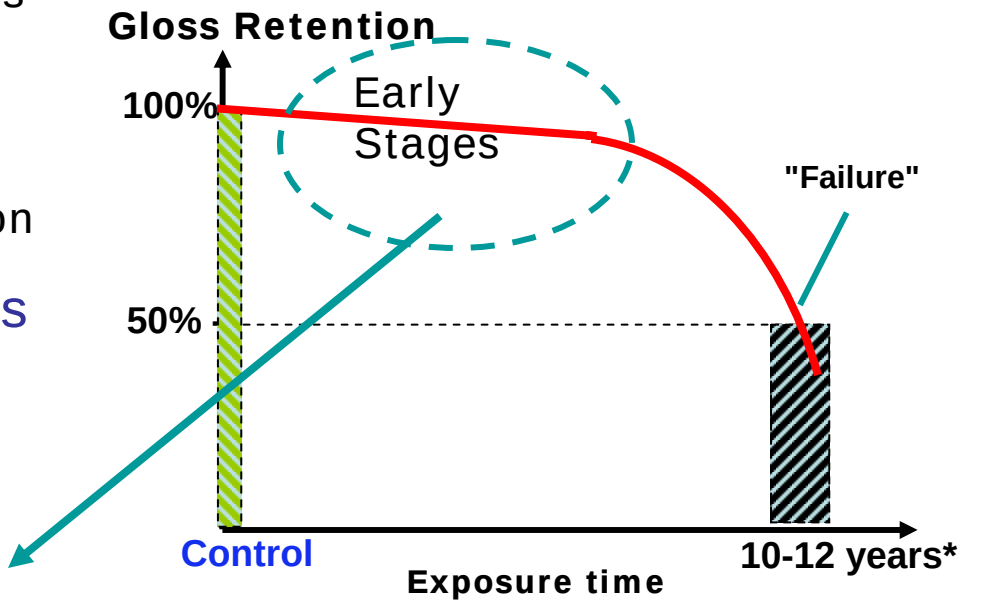
- **Appearance and durability are important attributes to the sale of a product**
  - How to characterize them?
  - How to relate them to material properties?
    - Surface morphology, mechanical properties, subsurface structure
  - What is needed to standardize measurements?

    Quantitative, objective
  - How to measure and predict them when weathered?

Current Methods for Assessing Failure

- Customer Acceptability -

- Gloss retention, color change
  - gloss measurement only collects specluar reflection
- Visual inspection
  - -light condition, human perception
- No well-established methods for predicting/understanding the failure mechanism.
  - degradation data in the early stage will be vital
  - need better characterizing tools especially optical scattering from early stage



*7 y for Automotive & interior coatings

Need Technical Idea on (Major Objectives)

- Develop advanced measurements methods **for quantifying appearance-related properties** (optical scattering) **and relating to physical properties** (surface morphology, subsurface microstructure, surface mechanical properties).
- Develop mathematical models for predicting optical properties **from measurements.**
  - including weathered, Scratch-damaged surfaces
- Integrate measurements and models in a computer rendering system **to create an accurate virtual representation** of the appearance of an object, and **predict service life** of coatings**.**

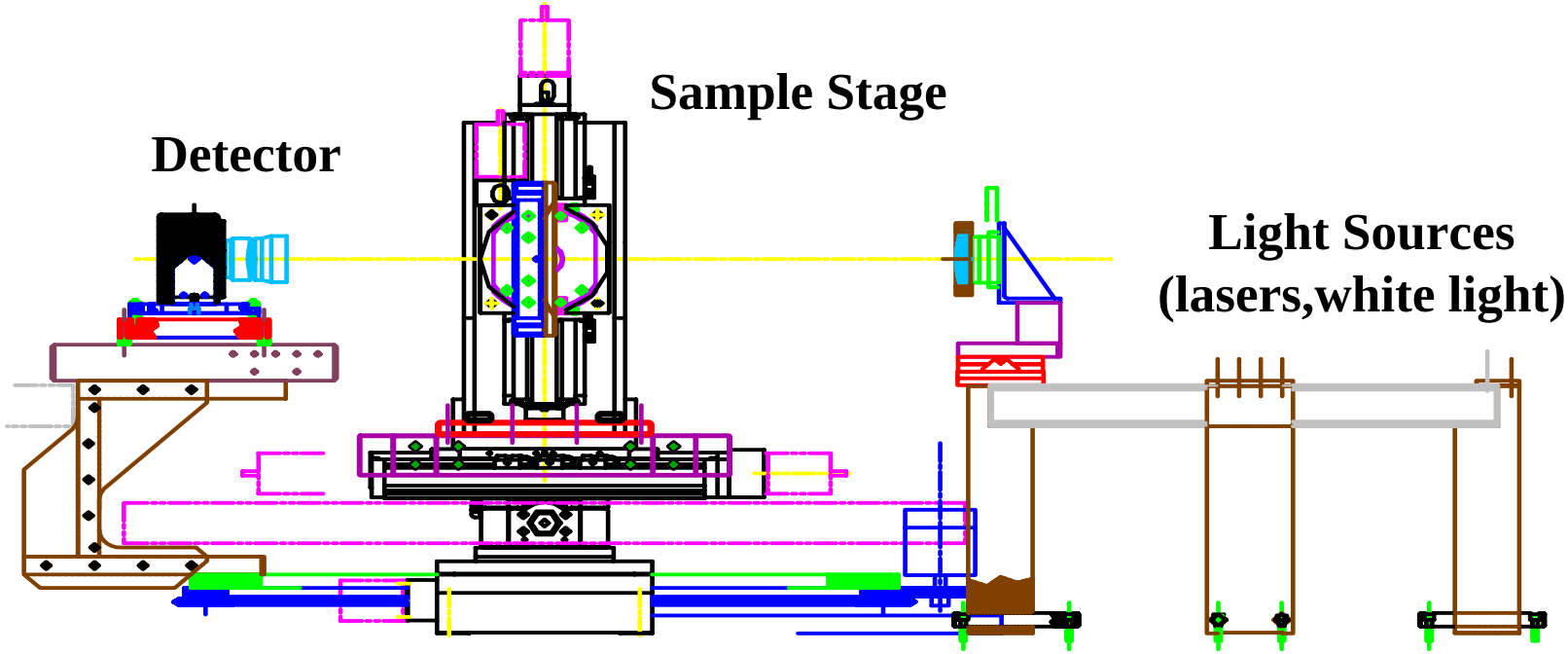
- Better Tools & Methods -

- Better Tool-

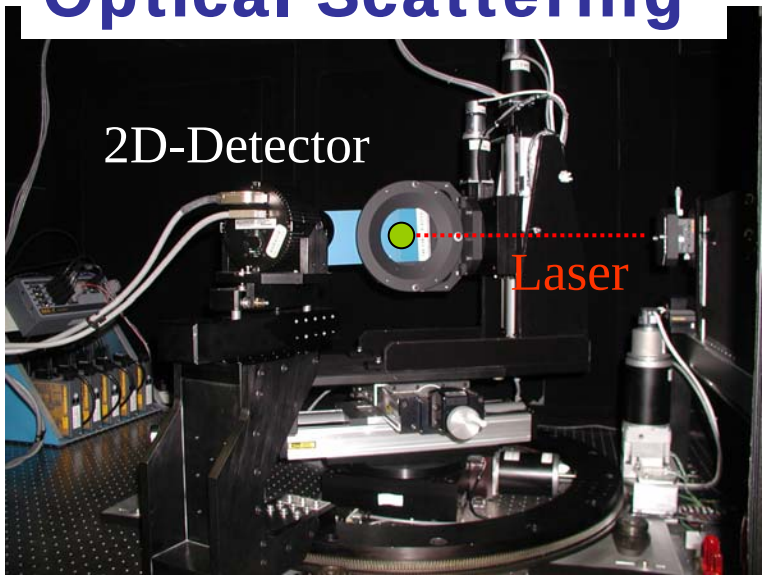
Optical Scattering Facility at BFRL

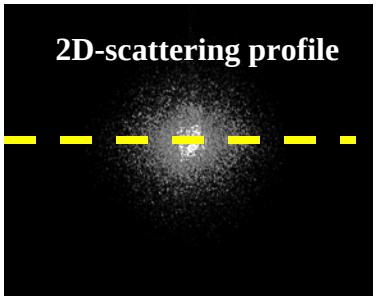
A308/226

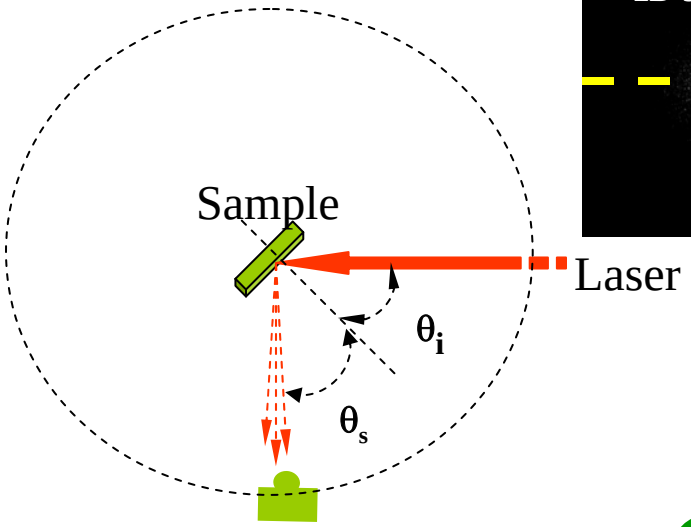
- ✓ Fully automated; five-axis goniometric sample stage
- ✓ Two-dimensional detector with a wide range of dynamic range
- ✓ In-plane/out-of-plane scattering
- ✓ Reflection/forward scattering
- ✓ ASTM wavelength range for color and gloss measurements



Optical Scattering

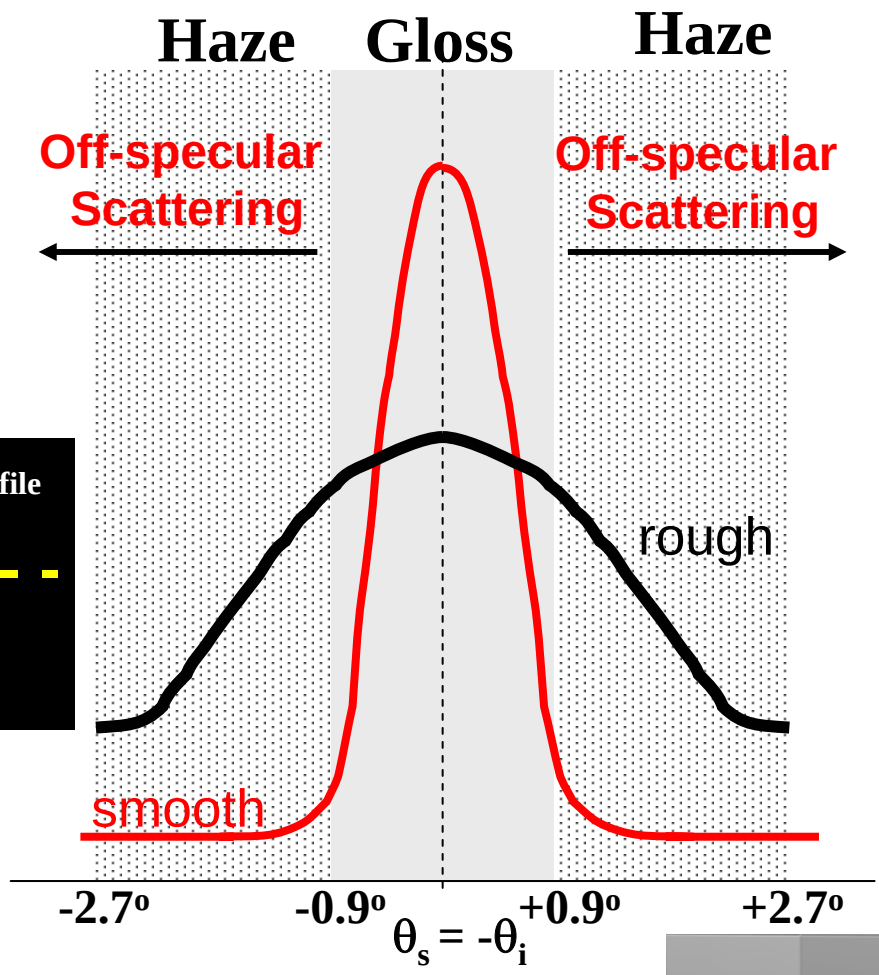




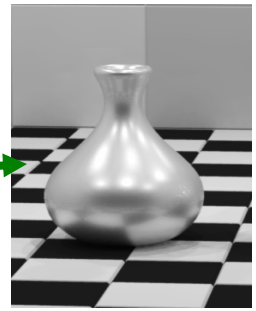


$\theta_s = -\theta_i$: **Specular angle**

Surface Appearance Measurement



Measuring entire scattering space

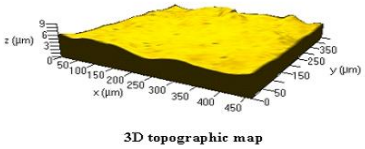


- Better Method-

What Have We Learned?

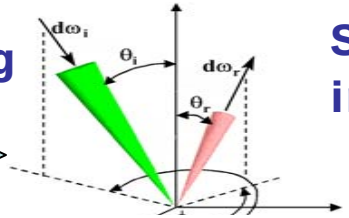
✓ NIST Appearance Project (1997-2001)

2D intensity projection



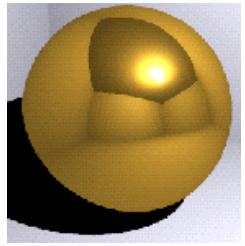
3D topographic map

Optical Scattering Model

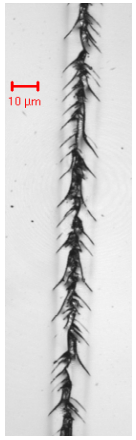


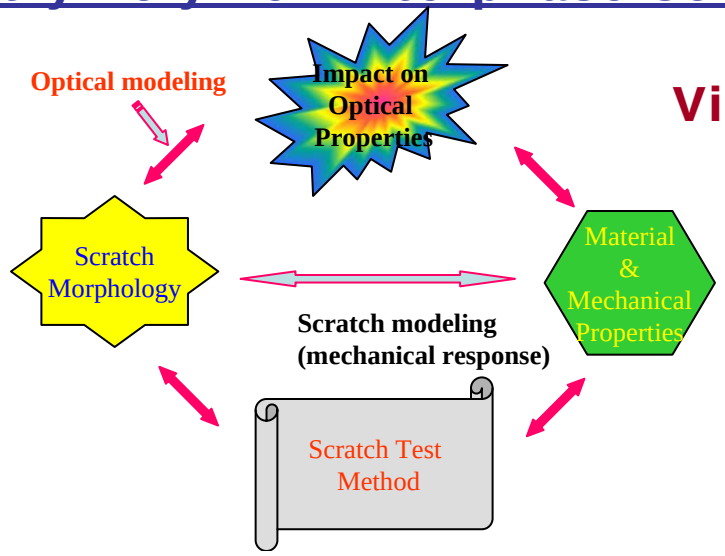
BRDF Scattering Function

Scattering interface

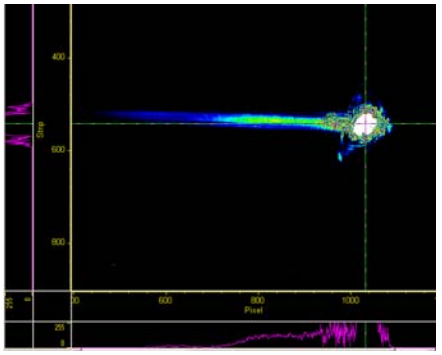


✓ NIST-Industry Polymer Interphase Consortium (2000-present)



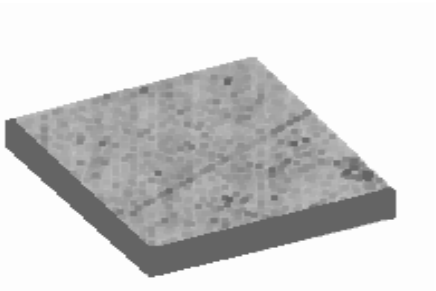


Visibility of Scratch

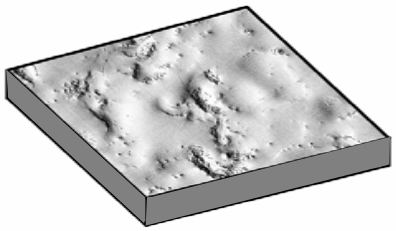


Surface Roughness and Optical Properties of a Clear Coating

Characterize Surface Roughness

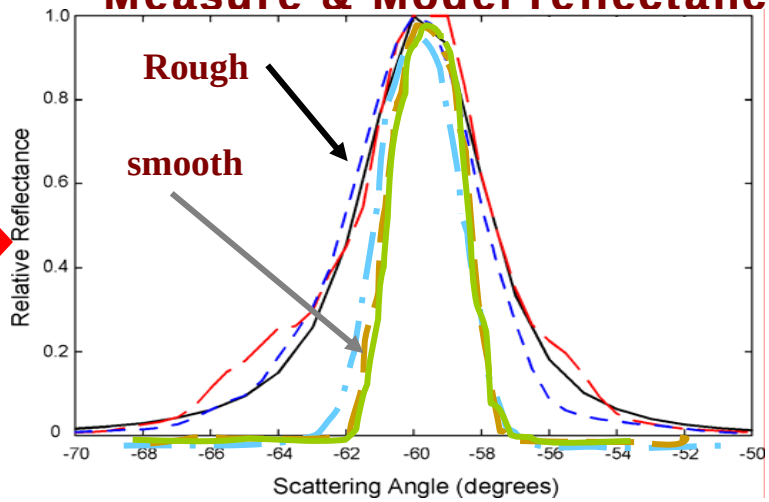


200 nm rms



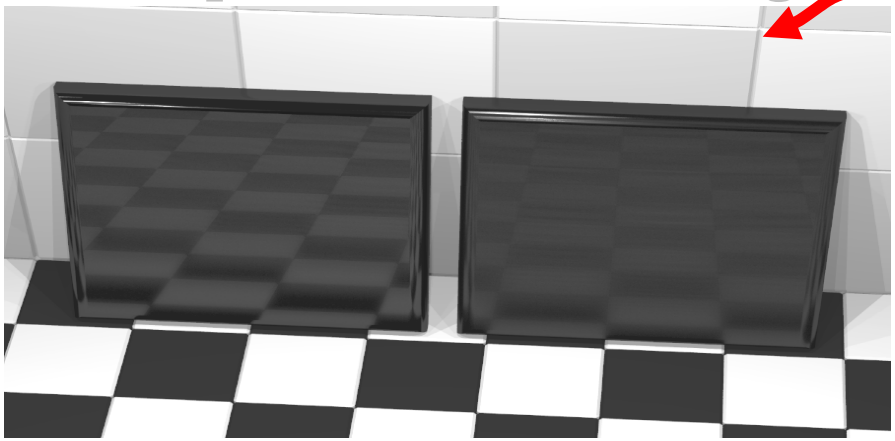
800 nm rms

Measure & Model reflectance

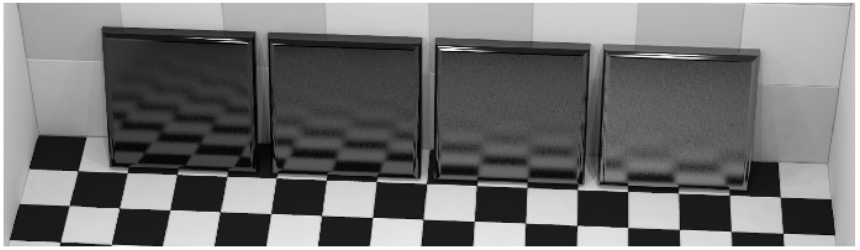


Computer-based Gloss Standards for Rendering

Computer Rendered Image



Gloss, D523

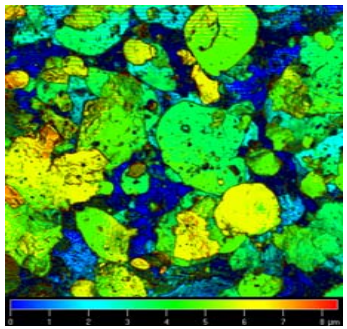


Haze (distinctness of image), D4039

Optical Scattering from Metallic Coatings

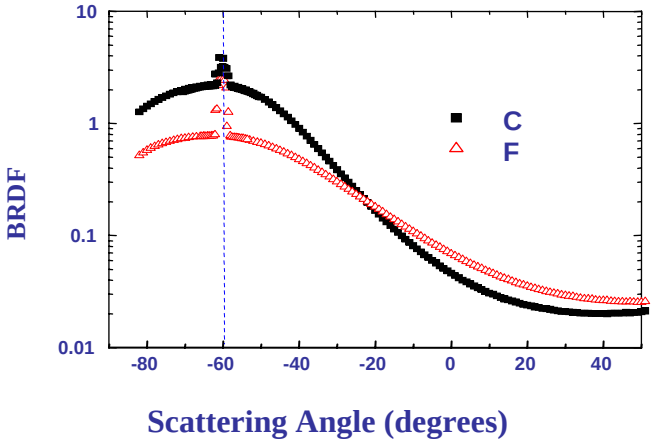
Virtual Comparison

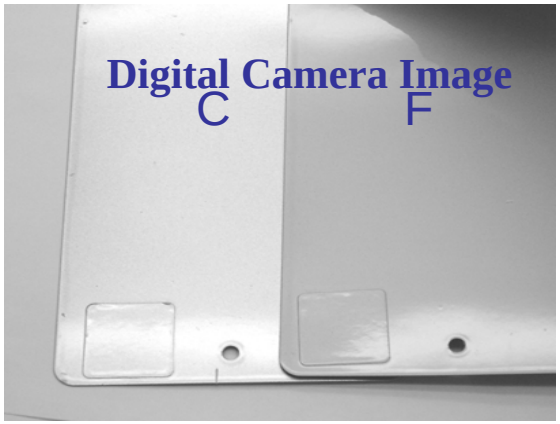
LSCM Data

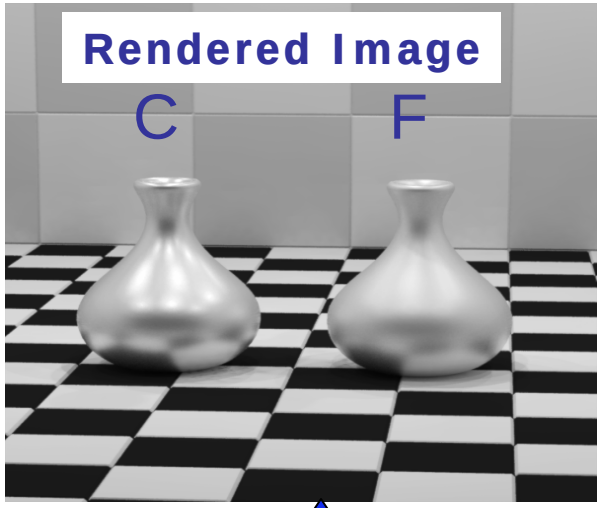


Ray Scattering Model

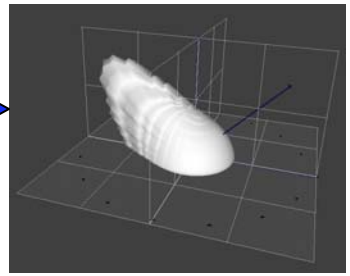
Measured Optical scattering Data

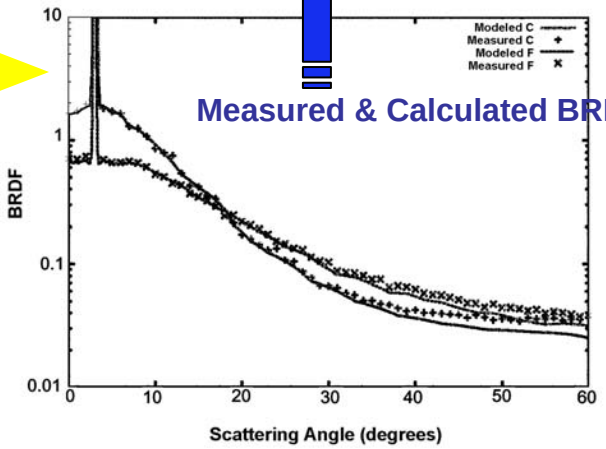






Beard Maxwell Model





Measured & Calculated BRDF

Used BMM to describe surface and subsurface scatter

Predicting Appearance Properties of Weathered Surfaces

- Build on the existing methods developed from “Appearance” and “NIST-Industry PIC” projects, with
  1. conducting quantitative measurements on surface morphology and optical scattering in the early stage of the degradation
  2. Analyzing the trend and scaling behavior in the data for different degradation times.
  3. Using optical modeling from predicted surface morphological data and comparing to the measured optical scattering data.
- Work with researchers in the fields of optical modeling and computer rendering from Universities. (Yale, U of Minn.)

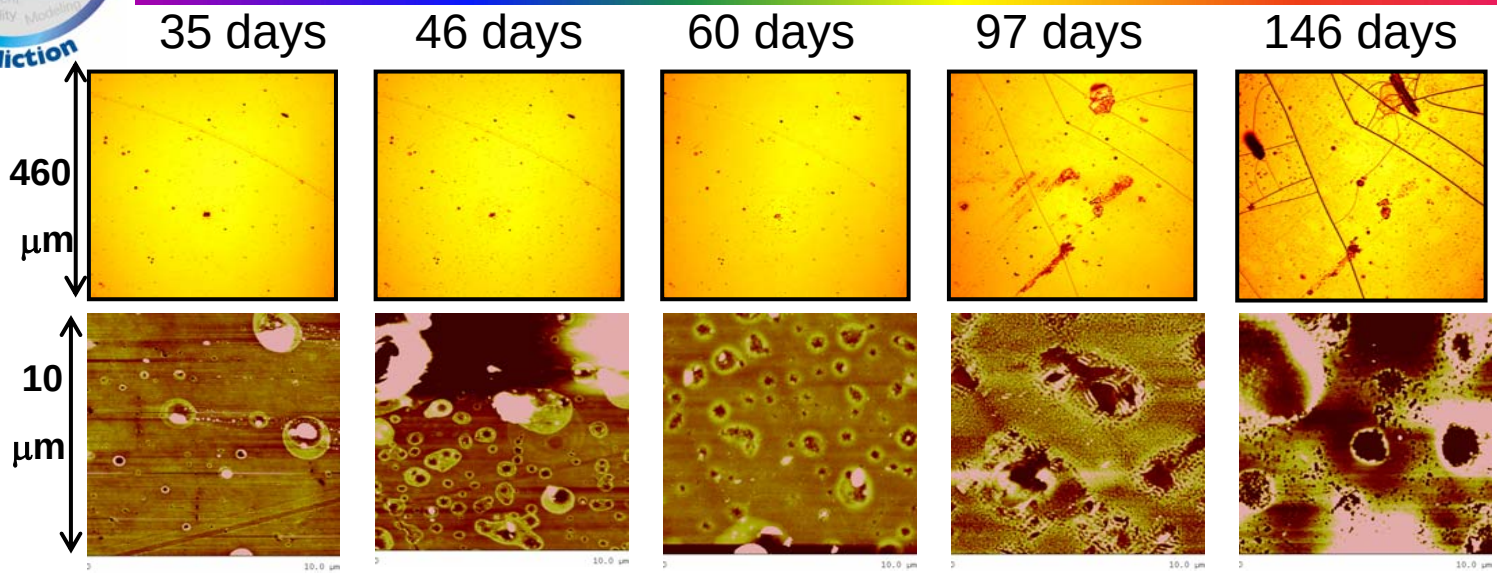
Physical and Optical Characterization on Weathered, Scratch-Damaged Surfaces

Yale University

Car Wash Damage

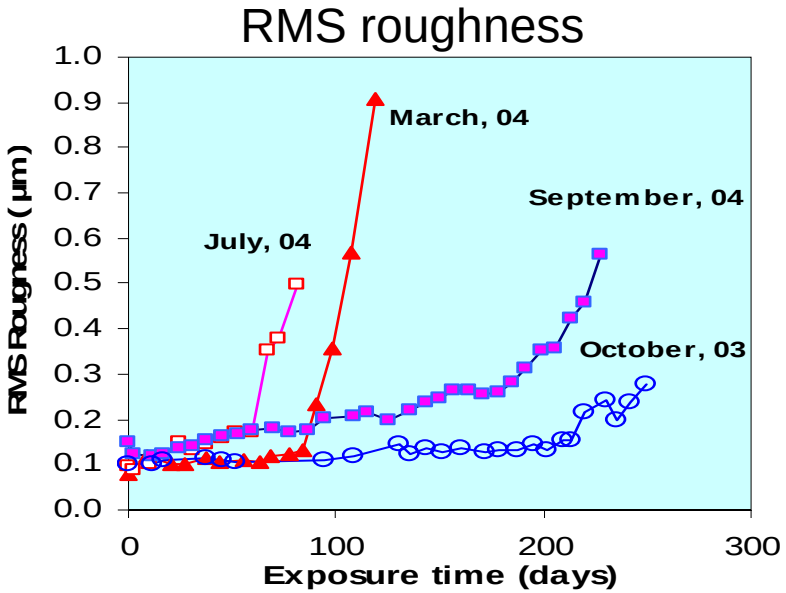
With input of accurate optical scattering (BRDF) and surface morphologic data

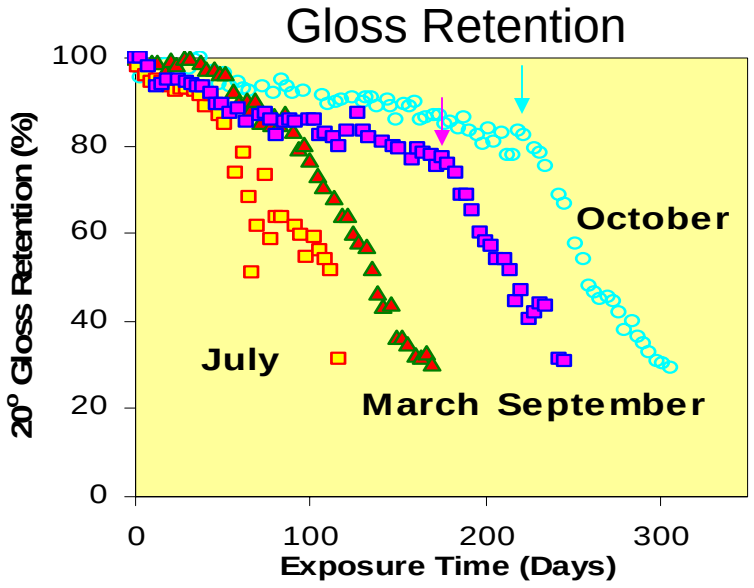
Surface Morphological and Gloss Values Change as a Function of Exposure Time



Outdoor Gaithersburg

Starting July 11, 2004

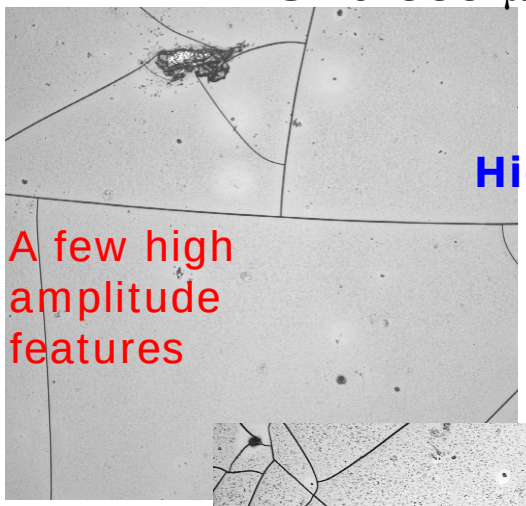




Relationship Between RMS Roughness and Gloss Values

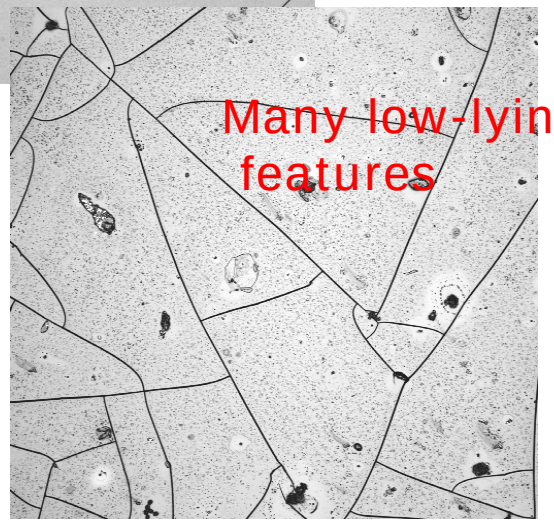
Same RMS roughness

RMS: 0.385 μm



A few high amplitude features

Higher gloss 88.3

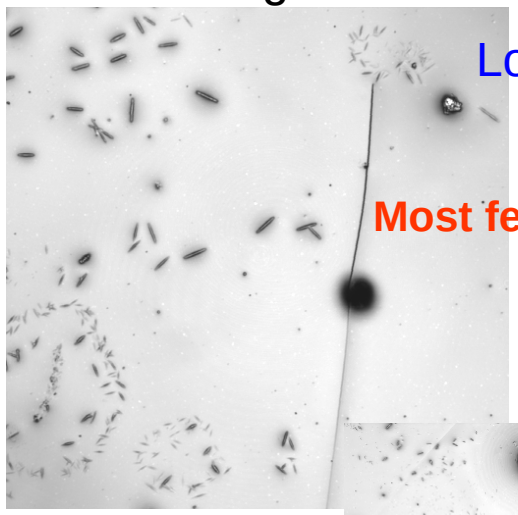


Many low-lying features

Lower gloss 80.4

Same gloss value

20o gloss value: 90



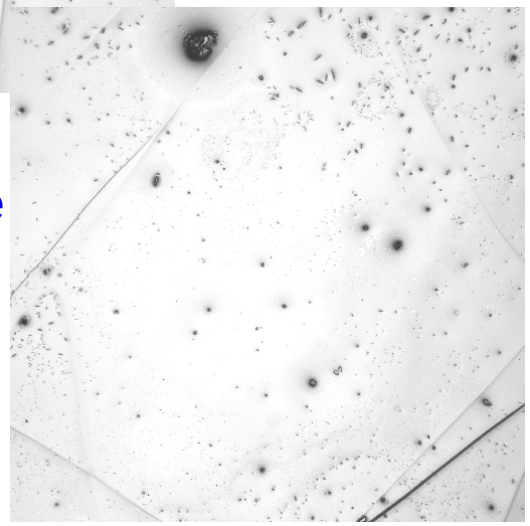
Lower RMS value

RMS: 0.193 μm

Most feature on surface

Higher RMS value

RMS: 0.407 μm

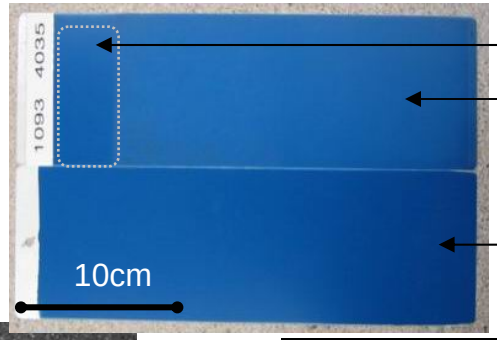


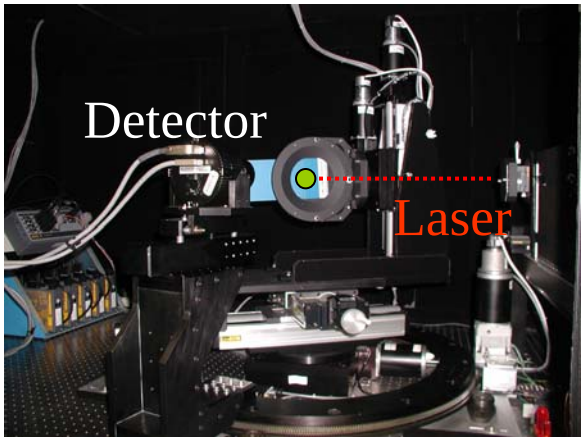
✓ Same Roughness but different gloss values

✓ Same gloss value may have different surface Roughness

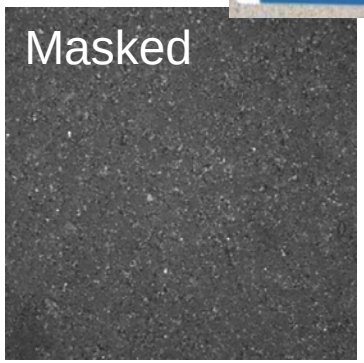
Optical Scattering from Weathered Coatings

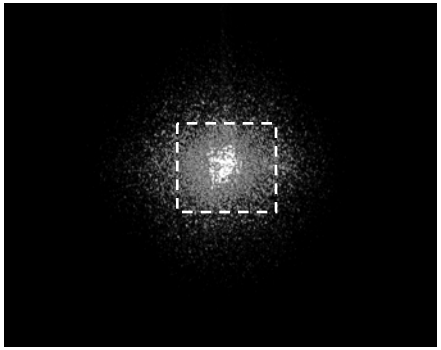
-With Kurt Wood, Arkema-

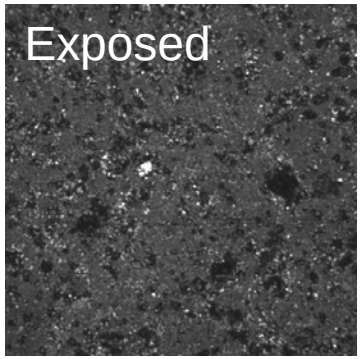


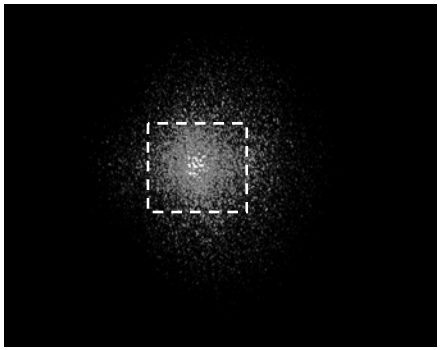


UV





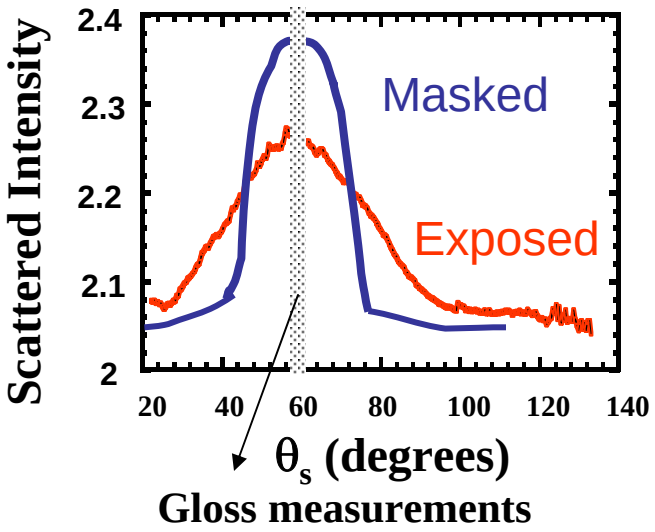




Surface morphology

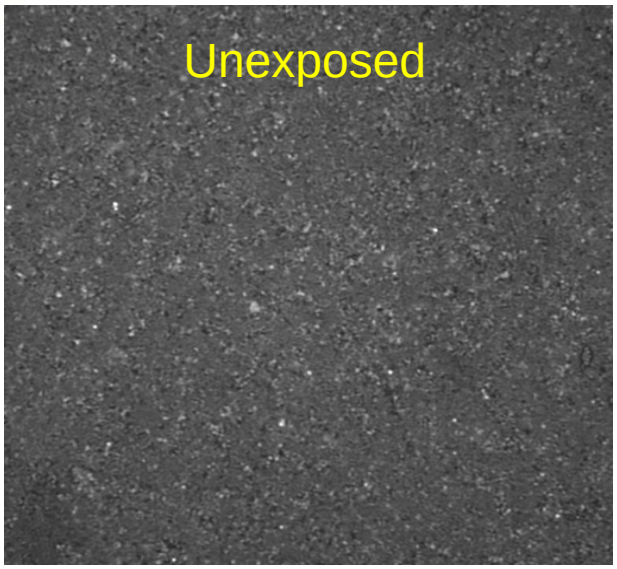
Scattering profile

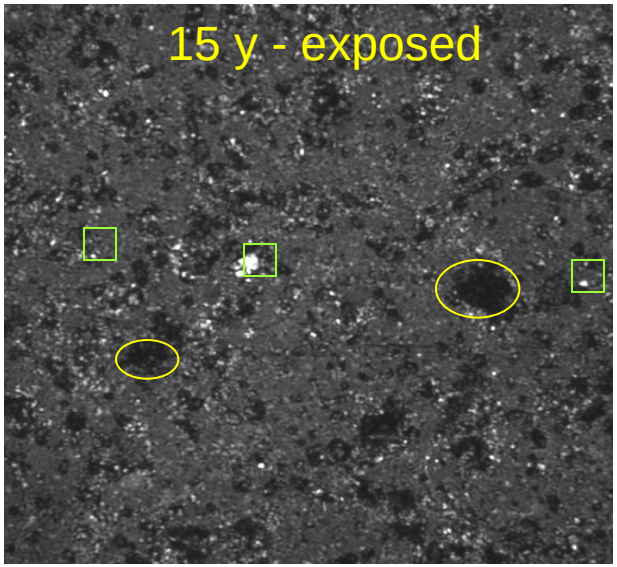
Scattering Function



Gloss measurements

Surface Morphological Changes Contribute to Changes in Appearance

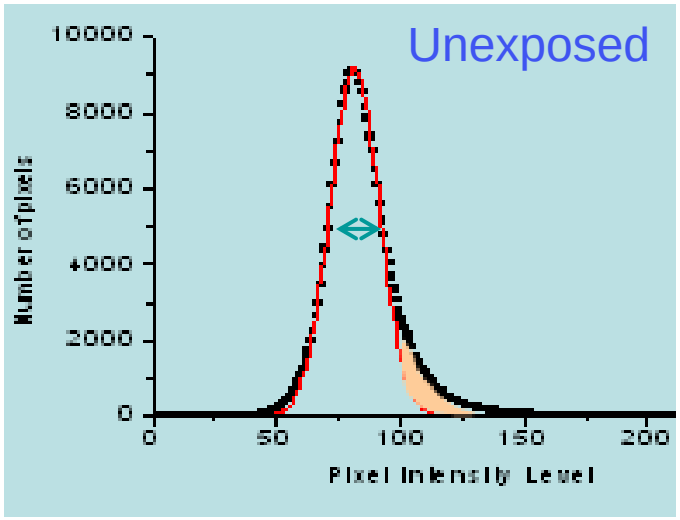


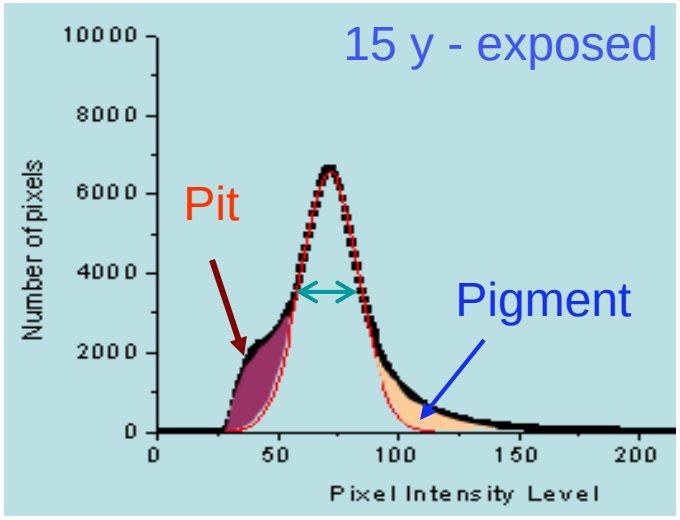


✓ **Surface Roughness**

✓ Pit

✓Pigment

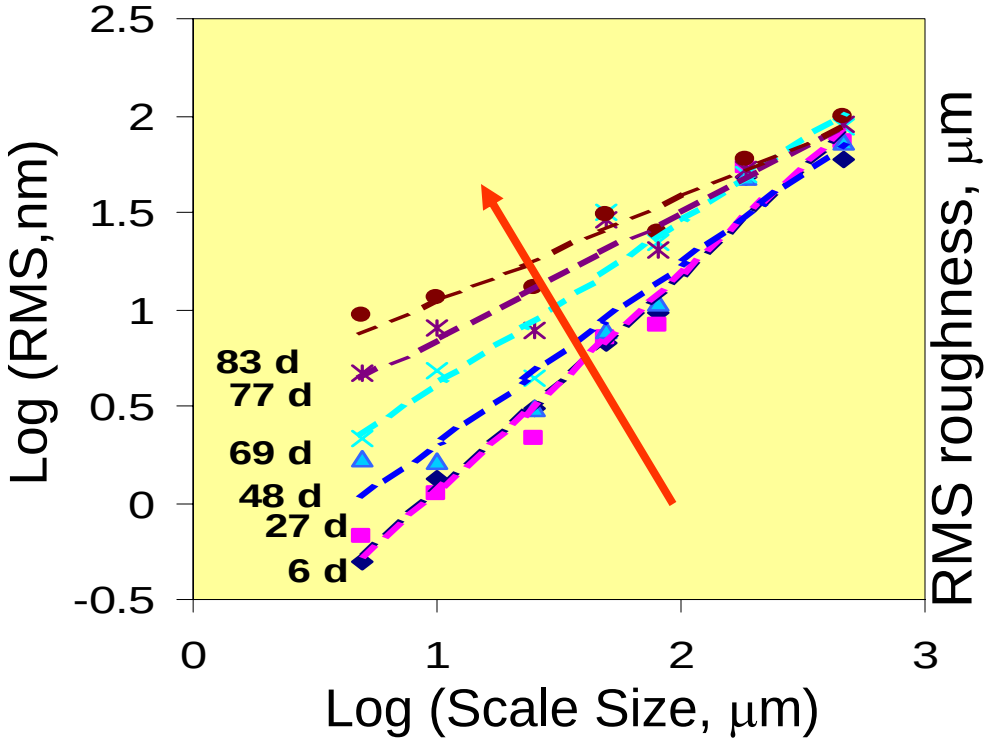




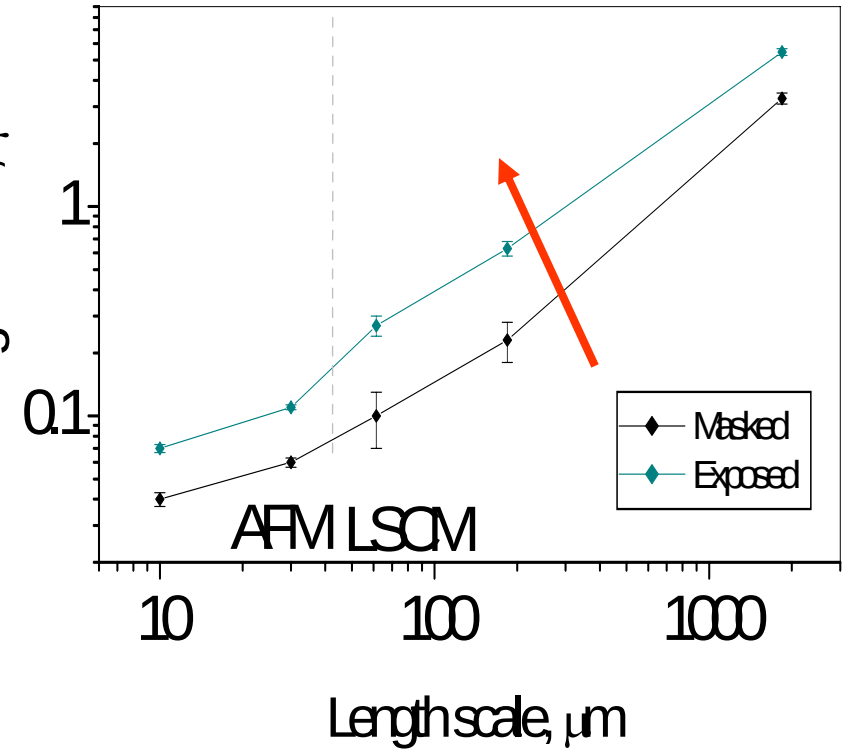
Specular intensity ⇓
off-specular (diffuse) intensity ⇑

Scaling Relationship
RMS Roughness Vs. Measured Length-Scale

Clear coating
Outdoor, MD



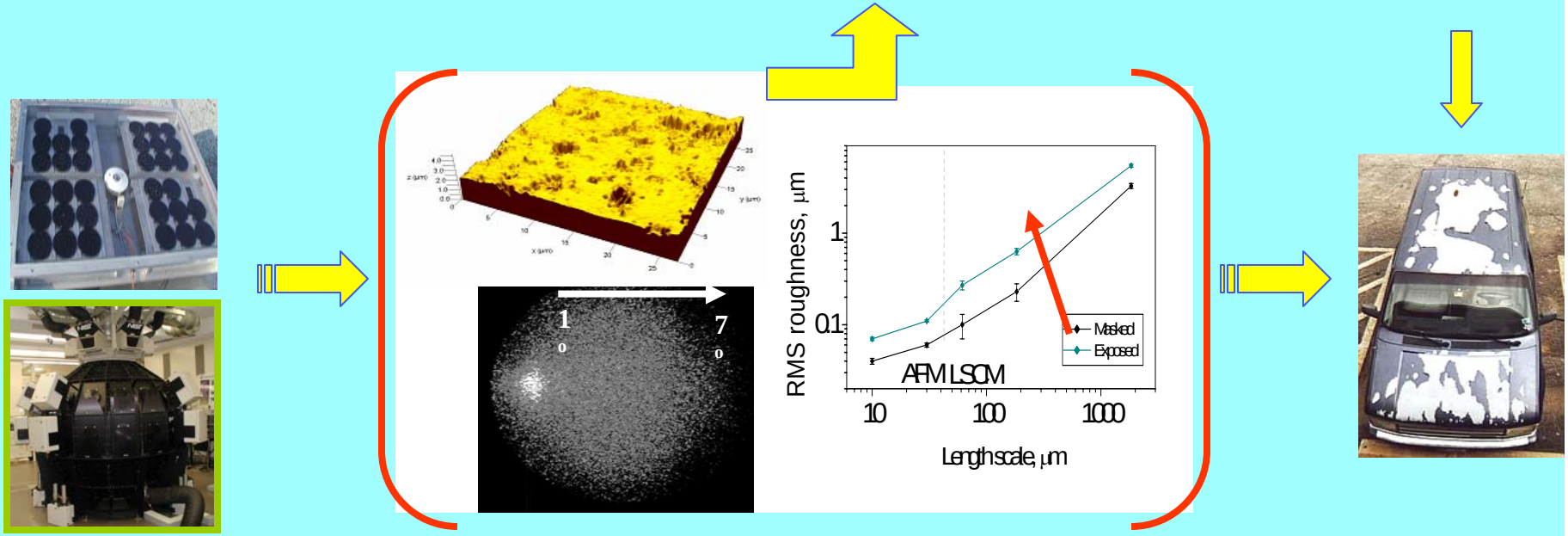
Pigmented coating
Outdoor, FL (15 years)



Scaling behavior was both observed in the early and late stages of weathered coatings

Predicting Appearance Properties from Weathered Surfaces

Feed data to computer rendering program and predict weathered data



Validating the prediction with accelerated weathering experiments

- Objectives -

Industry
Paint performance
<Outdoor weathering>

gloss loss
and color change

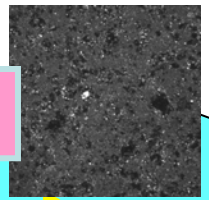
Macroscopic

10-15 years

Link between gloss and microscopic features

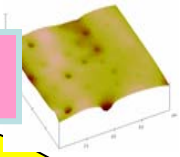
Shorten innovation time by predicting weatherability from early tests

Microscopic



Physical
Mechanical
Chemical
} changes

Nanoscopic



< 4 years

Indoor
Accelerated weathering
Precursor and modes of degradation

Understand origin of the degradation

Impact

- Provide critical understanding of the relationship between physical and optical properties of polymeric coating, predicting the service life of a product without a vast of testing.

- Reduce the cycle and time of “Time-to-Market” and help to design and achieve best performance, significantly reduce the costs associated with materials and production process.